

Black Stars and Gamma Ray Bursts

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Stars that are collapsing toward forming a black hole but are frozen near the Schwarzschild horizon are termed “black stars”. Collisions of black stars, in contrast to black hole collisions, may be sources of gamma ray bursts, whose basic parameters are estimated quite simply and are found to be consistent with observed gamma ray bursts. Black star gamma ray bursts should be preceded by gravitational wave emission similar to that from the coalescence of black holes.

It is well-known that, from an asymptotic observer’s viewpoint, a collapsing body is forever suspended just above its Schwarzschild radius. This picture may change with the inclusion of quantum radiation from the collapsing body as has been discussed from many viewpoints [1, 2, 3]. However, quantum effects change the picture on time scales given by the black hole evaporation time scale. For astrophysical bodies such as the sun, the evaporation time is $\sim 10^{66}$ years, which is $\sim 10^{56}$ times the present Hubble time. Hence for astrophysical purposes, we can ignore evaporative processes altogether and work within classical general relativity. Since any radiation from the collapsing body is redshifted by a large amount, the body will appear as a dark compact object. The object will appear black but will not be a black hole. We will call such an object a “black star”. In contrast, a “black hole” is a vacuum solution of Einstein’s equations and there is no matter distribution inside it except for the singularity at the origin.

When we watch for signatures from the collapse of astrophysical bodies, we take the asymptotic observer’s viewpoint, and hence, gravitational collapse always leads to black stars. In this brief note I point out that collisions of black stars can be a source of gamma ray bursts, and that such bursts are preceded by gravitational wave emission whose characteristics should be similar to those of black hole mergers. Even though the basic estimates for gamma ray bursts originating in black star collisions agree quite well with those for observed gamma ray bursts, this note, at least in its current form, can only be taken as a suggestion for pursuing this idea further. Observed gamma ray bursts have very complex features, and occur in many different sub-classes, each possibly having a different underlying origin. For details about gamma ray bursts, the reader is referred to the literature e.g. [4, 5, 6].

To distinguish between black stars and black holes, consider what happens when two black objects collide. If we receive photons from the collision, then the colliding objects were black stars because the empty spacetimes of two black holes would only create gravitational waves. If, however, we receive only gravitational waves from the colliding objects then they can either be primordial black holes or black stars that have not yet collided. Therefore, at least when black stars do collide, they can be distinguished from black holes by the nature of the radiation. The infall of matter on to a black star will also lead to

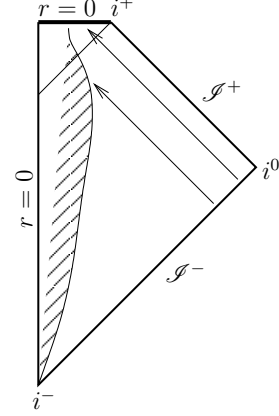


FIG. 1: Spacetime of a classical collapsing object (shaded region) that appears as a black star to an observer located near i^+ . Two null rays from \mathcal{I}^- are shown, one that collides with the black star and the other that does not. Similarly, an approaching second black star may or may not collide with the first black star depending on initial conditions.

electromagnetic emission due to collisions of the matter with the matter making up the black star; matter that is falling into a black hole will not emit electromagnetically except due to collision with other infalling matter, as in an accretion disk.

We now estimate the energy radiated from the collision of two black stars each of mass M . The radius of each of the black stars is $R = 2GM$ and so the density is

$$\rho = \frac{1}{8G^3M^2} \sim 10^{17} \left(\frac{M_\odot}{M} \right)^2 \text{ gms/cm}^3 \quad (1)$$

Therefore, if two black stars of mass M collide, it involves the collision of matter at high density, and will lead to radiation of photons and other light particles. Since the gravitational binding between all constituents in this system is very strong, we treat the collision as being totally inelastic. Then the initial kinetic energy gets converted to radiation resulting in the release of total energy

$$E \sim Mv^2 = 10^{48} \left(\frac{M}{M_\odot} \right) \left(\frac{v}{300\text{km/sec}} \right)^2 \text{ ergs} \quad (2)$$

Assuming that this energy is released in a light crossing time $\sim R/c = 2GM/c \sim 10^{-5}\text{sec}$, which is the only

relevant length scale in the problem, the emitted power is

$$P \sim 10^{53} \left(\frac{v}{300 \text{ km/sec}} \right)^2 \text{ ergs/sec} \quad (3)$$

Note that the power is independent of the mass M . Also, since the gravitational coupling is much weaker than electromagnetic interactions, almost all of the power will be in the form of photons. We can estimate the frequency of the photons by once again treating the collision as totally inelastic. Then every proton in the black star gets stopped on collision and the emitted photon energy is simply the initial kinetic energy of the proton

$$E_\gamma \sim m_p v^2 = 1 \left(\frac{v}{300 \text{ km/s}} \right)^2 \text{ keV} \quad (4)$$

Two black stars that approach each other with initial velocity, v , may or may not collide, depending on the precise initial conditions. This is most clearly seen on the spacetime diagram for a collapsing star (see Fig. 1). If the initial conditions are favorable, there will be frequent collisions; otherwise collisions will be rare. With our current knowledge, it is not possible to reliably estimate the frequency with which black star collisions occur.

Even though we cannot estimate the frequency of black star collisions, we do know that the frequency is smaller for smaller initial velocity since then the initial conditions are not suitable for the stars to collide. Also, we expect that the number of black stars falls off with higher velocity. These two arguments suggest that there should be a velocity at which black star collisions peak. In terms of gamma ray bursts, it implies that the gamma ray bursts should have a typical photon energy. Further, the total power emitted should scale with this photon energy as seen by dividing Eq. (3) by (4),

$$\frac{P}{E_\gamma} \approx 10^{62} \text{ sec}^{-1} \quad (5)$$

This formula does not depend on the mass of the colliding black stars and neither on their velocities, and hence is an invariant of the model. In a more realistic setting, however, black star collisions will, in general, not be head-on and may be affected by the surrounding environment. Also, the emitted radiation is not spherically

distributed because of the lack of spherical symmetry in the initial system and geometrical factors are needed to relate the emitted power to what an observer would see.

So far we have considered the collision of two black stars. Similar signatures may be expected from the collision of a black star and a normal star.

Next consider the collision of two black objects, each of mass M , where the matter does not collide but only the spacetimes collide. This can happen with black stars for which the initial conditions correspond to the later null ray in Fig. 1, or with primordial black holes for which collapsing matter is not present. In this case, all the initial kinetic energy – all 10^{48} ergs (Eq. (2)) of it – will be released in gravitational radiation, as the two spacetimes merge. However, the final coalescence takes an infinite time and will never be seen. Then we can never be sure if the gravitational signatures are from colliding primordial black holes or from black stars whose matter is yet to collide.

If an observed gamma ray burst is indeed due to colliding black stars, the burst should be preceded by gravitational wave radiation from the coalescing spacetimes of the black stars. The gravitational wave emission should be very similar to that calculated numerically for black hole collisions (*e.g.* [7]), and the final gravitational wave burst due to coalescence should be replaced by the gamma ray burst when the material of the black stars coalesce. Since the coalescence occurs in the strong gravitational field of the black stars, we expect electromagnetic ringing to accompany the gravitational ringing associated with the coalescing spacetimes. The characteristics of the emitted radiation will depend on the normal modes of the two black star system. Indeed, characteristics of the gravitational radiation preceding the gamma ray burst, together with the gamma ray burst, may allow us to infer the parameters of the colliding black stars and the initial conditions.

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